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## Final Report

*Project Title:*

# An Optimal Adaptive Routing Algorithm for Large-Scale Stochastic Time- Dependent Networks

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## Problem Addressed

The objective of this project is to develop an efficient algorithm and its computer implementation for the optimal adaptive routing problem that is practical in large-scale real-life networks, where a traveler could revise the route choice based upon en route traffic information. Existing adaptive routing algorithms are for explorative purpose and can only be applied to hypothetical and simplified networks. In this project, important changes will be made to make the algorithm practical in real-life networks, in three major areas: memory, running time, and realistic features. The algorithm will be implemented and tested on both randomly generated networks and a number of real-life large networks, including those from the Pioneer Valley Planning Commission (PVPC) of Massachusetts, and Stockholm, Sweden. The developed algorithm is an important building block for the route choice module of an advanced traffic prediction model, and is also the intelligent core of a route guidance system.

## Approach and Methodology

### *Modeling Framework*

We model the transportation network as a stochastic time-dependent (STD) network, where travel times on all links at all time intervals are jointly distributed random variables (that vary from day to day) with a finite number of discrete support points. A support point is a distinctive joint realization of all the random variables, and is usually represented by a day or an “average” day representing a group of similar days. It is assumed that travelers know *a priori* the joint probabilistic distribution and make decisions at nodes. The decision is what node  $k$  to take next, based on the current state  $x = \{j, t, I\}$ , where  $j$  is the current node,  $t$  is the current time interval index, and  $I$  is the real-time information, defined as a set of realized link travel times that are useful in making inferences about future link travel times. A routing policy  $\mu(x)$  is defined as a mapping from all possible states to decisions (next nodes). An optimal routing policy from a starting state to a destination optimizes a certain objective function, for example, minimizes the expected travel time or maximizes the on-time arrival probability.

### *Proposed Improvements*

We have made important changes to an existing algorithm (Gao and Chabini, 2006) to improve its performance in memory and running time.

**Piece-wise Linear Travel Time Representation** The dynamic link travel times will be represented by piece-wise linear functions instead of discrete values. In a typical application of the ORP problem, the study period (e.g., 6-9am) is divided into small time intervals with a length of shorter than 1 minute. The discrete joint link travel time distribution has been represented by a three-dimensional matrix with the dimension of (number of time intervals x number of support points x number of links). For real networks with hundreds of thousands of links, it is challenging if not impossible to store the distribution in the computer memory for a reasonably long study period (several hours). A piece-wise linear function, on the other hand, can store only the breaking points, and the travel time between two breaking points is derived by interpolation. The breaking points are generally sparsely distributed over the time, and the number of breaking points is much smaller than number of time intervals.

**Label-correcting** The existing algorithm is a label-setting algorithm that goes through all time intervals in decreasing order of time and requires link travel times to be strictly positive multiples of time interval length, and as a result, the time interval length needs to be smaller than the travel time

on the shortest link in the network. This usually results in a time interval length in seconds, and therefore a large number of time intervals. We designed a label-correcting algorithm that only requires the travel times to be non-negative, and thus the time interval length can be greater than link travel times. As such the number of time intervals can be reduced, and running time reduced. Please note that the time interval length cannot be too long, as it will compromise the optimality of the solution.

Various data structures have been tested for the scan eligible lists in the label correcting algorithm, including FIFO, 2Que, and de-queue.

**Turn-based** Waiting at nodes and cycles are unlikely to happen in real-life network due to travelers' aversion to such behaviors. We modified the algorithm to be link based where a state is defined as a triplet of link, time and real-time information. The turning movement from link to link can thus be associated with turning penalties to penalize waiting and u-turns.

**Customized study period length** is deployed when there is prior knowledge on the travel time of a trip, for example, from an observed GPS trace. This is especially useful for a one-to-one problem that is usually present in choice set generation for route choice modeling.

## Conclusions

The worst-case runtime of the label-correcting algorithm is cubic in the number of links and square in the number of time periods. However, computational tests on both random networks and a real-life network from Western Massachusetts with over 28,000 links show that the runtime is almost linear in both.

It is found that 2Que is the most efficient data structure for the algorithm, with roughly a four-time speed-up compared with FIFO queue.

With all the improvements, the algorithm is applied in route choice set generation for a network in Stockholm, Sweden with over 5000 links and 56 support points. The trip length varies between 10 to 30 minutes. The runtime per destination is about 4 minutes with a time interval length of 12 seconds. We are able to generate choice sets of routing policies with an average size of 100 for 125 destinations in about 2 weeks using a regular PC. This is acceptable for off-line planning applications.

## Outcomes

### *Journal Publications*

Ding-Mastera, J. and Gao, S. An Optimal Adaptive Routing Algorithm for Large-Scale Stochastic Time-Dependent Networks. *Transportation Research Part C*. In preparation.